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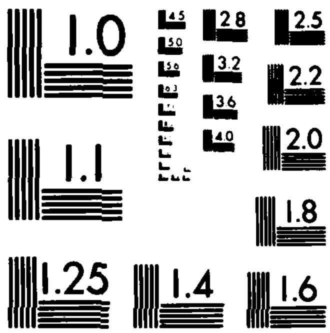

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NRL Memorandum Report 5549

Electrostatic Ion Cyclotron Instability Due to a Nonuniform Electric Field Perpendicular to the External Magnetic Field

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May 28, 1985

This work was supported by the National Aeronautics and Space Administration and the Office of Naval Research.

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REPORT DOCUMENTATION PAGE

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2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
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4. PERFORMING ORGANIZATION REPORT NUMBER(S): NRL Memorandum Report 5549	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Naval Research Laboratory; 6b. OFFICE SYMBOL (If applicable): Code 4780	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Washington, DC 20375-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: NASA and ONR; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Washington, DC 20546 Arlington, VA 22217	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. (See page ii); PROJECT NO.; TASK NO.; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification) Electrostatic Ion Cyclotron Instability Due to a Nonuniform Electric Field Perpendicular to the External Magnetic Field

12. PERSONAL AUTHOR(S)
Ganguli, G.,* Lee, Y.C.,*† and Palmadesso, P.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM ____ TO ____	1985 May 28	22

16. SUPPLEMENTARY NOTATION *Science Applications International Corporation, McLean, VA 22102
†Present address: University of Maryland, College Park, MD 20740 (Continues)

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Nonlocal; Localized electric field; Ion-cyclotron turbulence; Positive-negative energy

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

We suggest a new mechanism that can destabilize the kinetic ion cyclotron waves in the presence of a nonuniform electric field perpendicular to the uniform ambient magnetic field. In the absence of the electric field the mode energy is positive while in the presence of a uniform electric field the mode energy could be negative. However, when the electric field is nonuniform, it is possible for a finite region to be of negative wave energy surrounded by regions of positive wave energy. A nonlocal wave packet couples the two regions so that a flow of energy from the region of negative wave energy to the region of positive wave energy will cause the mode to grow. This gives rise to the instability.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: P. J. Palmadesso	22b. TELEPHONE (Include Area Code): (202) 767-6780; 22c. OFFICE SYMBOL: Code 4700.1P

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete.

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10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61153N		RR033-02-44	DN380-475
		W-15494	DN430-607

16. SUPPLEMENTARY NOTATION (Continued)

This work was supported by the National Aeronautics and Space Administration and the Office of Naval Research.

CONTENTS

ELECTROSTATIC ION CYCLOTRON INSTABILITY DUE TO A NONUNIFORM ELECTRIC FIELD PERPENDICULAR TO THE EXTERNAL MAGNETIC FIELD

I. Introduction

The ion cyclotron instability has been of importance to both space and laboratory plasmas. In most previous studies, field aligned currents or ion beams have been cited as the driving mechanism[1]. Recently some laboratory experiments[2] have reported ion cyclotron instability in circumstances in which neither of the above mechanisms provides a satisfactory free energy source, and the existence of a two dimensional electric field is conjectured to play a role. Further, unstable ion cyclotron waves have been reported in connection with double layers[3] and electrostatic shocks[4]. In all these cases a localized electric field perpendicular to the external magnetic field is an intrinsic feature of the equilibrium. The purpose of this letter is to report a new kinetic ion cyclotron instability driven by a nonuniform electric field perpendicular to the external magnetic field which could be of importance to the situations referred above[2-4].

II. Theory and Results

Using physical arguments we first establish that an equilibrium characterized by an external uniform magnetic field B_o (in the z direction) perpendicular to an external nonuniform electric field $E_o(x)$ (in the x direction) is unstable to the electrostatic ion cyclotron waves. The local dispersion relation of the electrostatic ion cyclotron waves[5] is given by,

$$D(\omega,k) = 1 + \tau + \Sigma\ \Gamma_n(\underline{b})\left(\frac{\omega}{|k_\parallel|v_i}\right)Z\left(\frac{\omega - n\Omega_i}{|k_\parallel|v_i}\right) + \tau\ \left(\frac{\omega}{|k_\parallel|v_e}\right)Z\left(\frac{\omega}{|k_\parallel|v_e}\right) = 0 \qquad (1)$$

where $(k\lambda_i)^2 << 1$ is assumed. Also $\tau = T_i/T_e$, $v_{i,e}$ are the ion and electron thermal velocities, $\Omega_i = eB_o/m_ic$ is the ion gyro radius, $k_\parallel$ and $k_\perp$ are the parallel and perpendicular components of the wave vector (with respect to B_o), $\Gamma_n(\underline{b}) = I_n(\underline{b})\exp(-\underline{b})$, $\underline{b} = k_\perp^2\rho_i^2/2$, $\rho_i = v_i/\Omega_i$ and I_n are the modified Bessel's functions. Setting $k_\parallel \to 0$ one obtains the dispersion relation for the Bernstein modes (BM),

$$D_{BM}(\omega,k) = 1 - \Gamma_o - \sum_{n>0} \frac{2\omega^2}{\omega^2 - n^2\Omega^2}\Gamma_n = 0, \qquad (2)$$

Manuscript approved January 30, 1985.

and if $(\omega/v_e) \ll k_\parallel \ll (\omega - n\Omega_i)/v_i$, then one gets the corresponding expression for the ion cyclotron modes (IC),

$$D_{IC}(\omega,k) = 1 + \tau - \Gamma_o - \sum_{n>0} \frac{2\omega^2\Gamma_n}{\omega^2 - n^2\Omega^2} = 0. \tag{3}$$

For the time being we neglect all the natural dampings. In the local approximation the energy density of the electrostatic waves is proportional to $\partial(\omega D)/\partial\omega \approx \omega\partial D/\partial\omega$. Thus the energy density U, of both the BM & IC waves is given by

$$U \propto \omega(\partial D/\partial\omega) = \omega \left\{\sum_{n>0} \omega \frac{4\Gamma_n n^2\Omega^2}{(\omega^2 - n^2\Omega^2)^2}\right\} = \omega^2\sigma(\omega),\ \sigma > 0. \tag{4}$$

Clearly U is positive definite and thus the waves are positive energy waves.

We now introduce a uniform electric field E_o in the x direction. This initiates a drift of magnitude $V_E = cE/B$ in the y direction. Thus, other than a Doppler shift (i.e., $\omega \to \omega_1 = \omega - k_y V_E$) there is no change in the dispersion relations given in (2) and (3). The energy density of the Doppler shifted waves U', is given by,

$$U' = \omega\, \omega_1 \sigma(\omega_1) \,. \tag{5}$$

While U is positive definite U' can be negative provided $0 < \omega < k_y V_E$ thereby giving the waves a negative energy density.

Clearly a uniform electric field perpendicular to the external magnetic field can convert the positive energy waves into negative energy waves. However, as long as the electric field is uniform, a transformation to another frame moving with a velocity V_E will enable the waves to get back the positive energy character. This is no longer possible once the electric field is nonuniform. For example consider a specific model for the external electric field,

$$E_o(x) = \begin{cases} E_o\,, & -\frac{L}{2} < x < \frac{L}{2} \\ 0, & \text{otherwise} \end{cases} .$$

As the main objective of this letter is to demonstrate and discuss the new instability we have chosen a somewhat idealized electric field profile for relative ease in computation and transparency of the physics involved. Since E is localized in x over a distance L ($L > \rho_i$) , one finds that a negative wave energy region I, is surrounded by positive wave energy regions II (See Figure 1). A nonlocal wave packet can couple these regions and a flow of energy from region I to region II can enable the mode to grow. This gives rise to the instability. This is essentially a nonlocal instability with no local limit. The negative energy wave framework has been previously used[6] to explain other plasma instabilities at a local level. Ours is a nonlocal instability similar in concept with Lau[7] et. al who apply this concept to an astrophysical problem.

Since the x direction is nonuniform we use nonlocal differential equations[5] in the regions I and II to analyze this case. Dissipation processes such as Landau damping are now included.

<u>REGION - I:</u>
$$\left\{\frac{\partial^2}{\partial\xi^2} + \kappa_I^2\right\} \Phi_I(\xi) = 0, \tag{6}$$

<u>REGION - II:</u>
$$\left\{\frac{\partial^2}{\partial\xi^2} + \kappa_{II}^2\right\}\Phi_{II}(\xi) = 0, \tag{7}$$

where $\xi = x/\rho_i$, $\kappa_I^2 = Q_I/A_I$ and

$$Q_I = 1 + \tau + \Sigma\, \Gamma_n \left(\frac{\omega_1}{|k_\parallel|v_i}\right)Z\left(\frac{\omega_1 - n\Omega_i}{|k_\parallel|v_i}\right) + \tau\left(\frac{\omega_1}{|k_\parallel|v_e}\right)Z\left(\frac{\omega_1}{|k_\parallel|v_e}\right), \tag{8}$$

$$A_I = -\frac{1}{2}\sum_n \Gamma_n'\left(\frac{\omega_1}{|k_\parallel|v_i}\right)Z\left(\frac{\omega_1 - n\Omega_i}{|k_\parallel|v_i}\right), \tag{9}$$

$$\Gamma_n' = \frac{\partial}{\partial b}\Gamma_n, \; b = k_y^2\rho_i^2/2 .$$

κ_{II}^2 is identical to κ_I^2 if ω_1 is replaced by ω . The solutions in region I is,

$$\Phi_I(\xi) = \Phi_{oI}\cos(\kappa_I\xi), \tag{10}$$

while in region -II it is,

$$\Phi_{II}(\xi) = \Phi_{oII}\exp(i\kappa_{II}\xi + i\delta) , \tag{11}$$

where Φ_{oI},Φ_{oII} and δ are constants. Demanding that the logarithmic derivative of the solutions be continuous at $\xi = L/2\rho_i$ we obtain the nonlocal dispersion relation,

$$-\kappa_I \tan(\kappa_I/2\varepsilon) = i\kappa_{II}, \tag{12}$$

where $\varepsilon = \rho_i/L$. Given the parameters, we use a numerical root finder to solve (12) for the complex frequency ω. As a boundary condition we demand that the solution vanish at ∞, i.e., $\mathrm{Im}(\kappa_{II}) > 0$. It should be remarked that since the electric field has a sharp profile our treatment at the second order differential equation level can be improved by employing an integral equation formulation. However, such a formulation is mathematically cumbersome and does not provide a simple and clear interpretation of the physics involved. Thus, for the time being, we stress simplicity and clarity over greater accuracy which will be provided in the future.

Figure 2 is a plot of the real and imaginary parts of the frequency, ω_r/Ω and γ/Ω, against b for $\tau = 0.$, $V_E = 2.9v_i$, $\varepsilon = 0.3$, $u = k_\parallel/k_y = 0.001$ and $\mu = m_i/m_e = 1837$. The instability exists only for a very narrow band of k_y thereby making it very coherent. The real part of the frequency is large ($\omega \sim 1.60\Omega_i$) compared to the first harmonic. Also the instability peaks for $k\rho_i \sim 0(1)$. These features are in keeping with the observations of Mozer[4] et. al.

Figure 3 is a plot of γ/Ω_i against u for $\tau = 0$, 0.5 and 1.0 and b = 0.57 while other parameters are similar to the Figure 2. Clearly this instability prefers small u (perpendicular propagation) ,again in keeping with Mozer et. al[4]. For $\tau = 0$, u can get as high as 0.15 but for higher τ the value of u is even smaller. For u ~ 0.01 larger τ implies

more electron Landau damping which reduces the growth rate.

Figure 4 is a plot of ω against ε for $u = 10^{-4}$ and other parameters similar to Figure 2. Our theory at the second order differential equation level is valid for $\varepsilon < 1$ (i.e., $\rho_i < L$) . For $\rho_i > L$ situations an integral equation formulation will become necessary. For most of the laboratory experiments $L \sim (2 \text{ to } 3)\rho_i$, for which our theory holds. Figure 3 indicates that the instability is more severe for smaller L (i.e., for strongly localized electric fields) and disappears for $L > 7\rho_i$, for the given parameter range.

Figure 5 is a plot of γ/Ω_i against $\overline{V}_E(= V_E/v_i)$ for b = 0.57, $\tau = 1.0$, $\varepsilon = 0.3$ and $u = 10^{-4}$. The instability exists for $\overline{V}_E$ between 2.8 and 3.2 peaking at around 3. The peak value of $\overline{V}_E$ in both Mozer et al.[4] and Merlino et al.[3] is well above the minimum necessary for this instability. Further, $\omega_1 \approx - \Omega_i$ is necessary for the onset.

III. Conclusions

In this letter we give a new mechanism that can explain the occurance of the short wavelength ($k\rho_i \sim 1$) turbulence around the ion cyclotron frequency in the presence of a nonuniform electric field perpendicular to the external magnetic field. This instability is driven by the coupling of the positive and negative energy ion cyclotron waves. Ion cyclotron turbulence has been observed associated with shocks[4] in the magnetosphere and with double layers[3] both in laboratory and space plasmas, where a strongly localized electric field perpendicular to the magnetic field is present. Thus the instability mechanism described in this letter could play a significant role in such situations. We would also like to note that the mechanism of the instability given here is general and can be applied to other instabilities as well. For example, a study of lower hybrid wave excitation by this mechanism is in progress and will be the subject of a future article

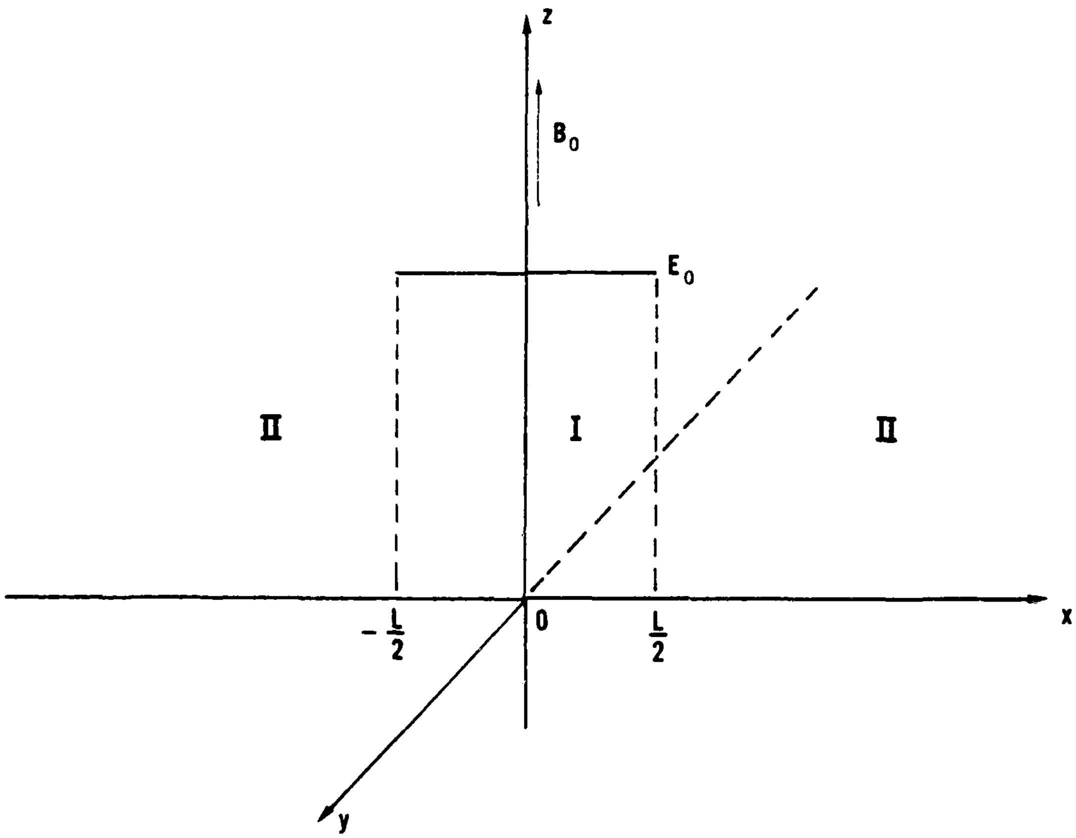

Figure 1. A sketch of the electric field model.

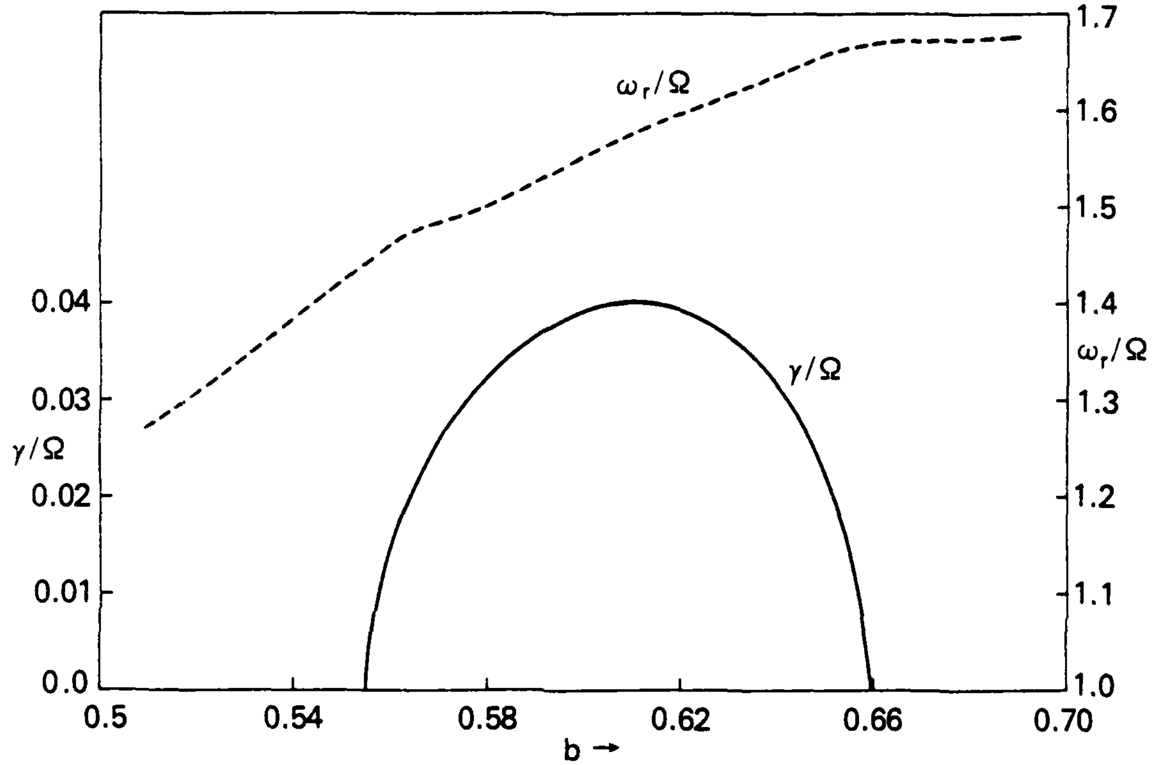

Figure 2. A plot of the real and imaginary part of the wave frequency ω_r/Ω_i and γ/Ω_i against b. Here $\tau = 0$, $\overline{V}_E = 2.9$, $\varepsilon = 0.3$, $\mu = m_i/m_e = 1837$ and $u = 10^{-3}$.

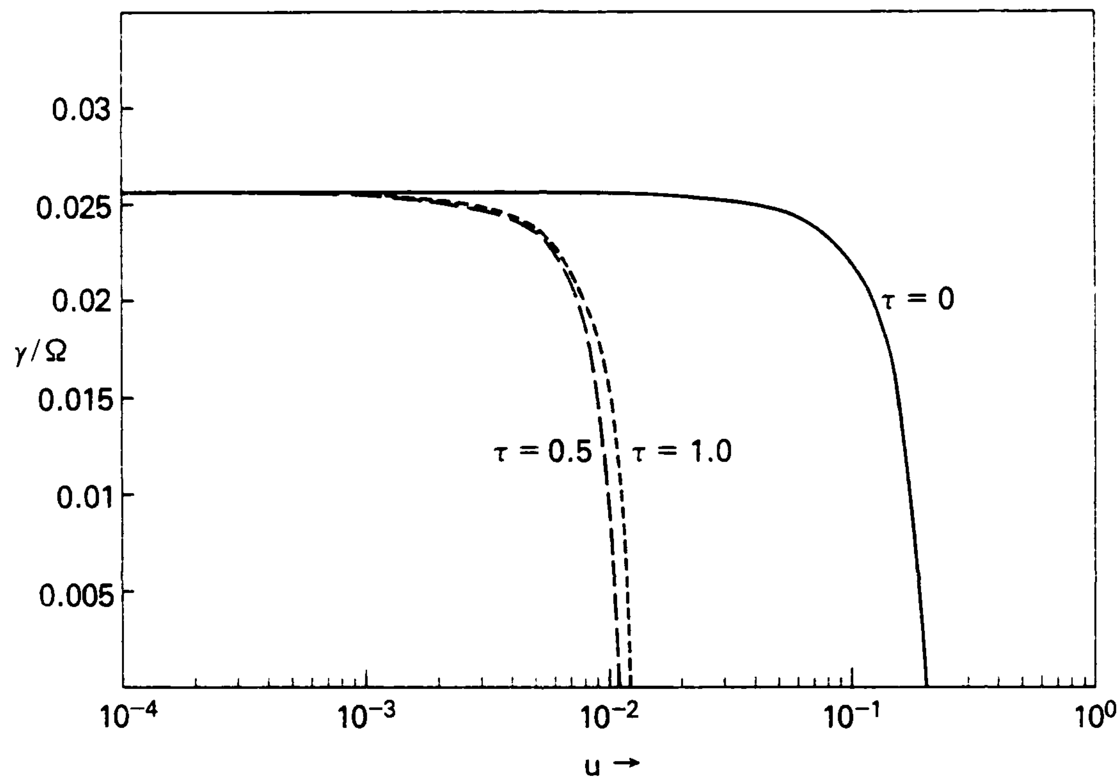

Figure 3. A plot of γ/Ω_i against u. Here b = 0.57 and other parameters similar to Figure 1.

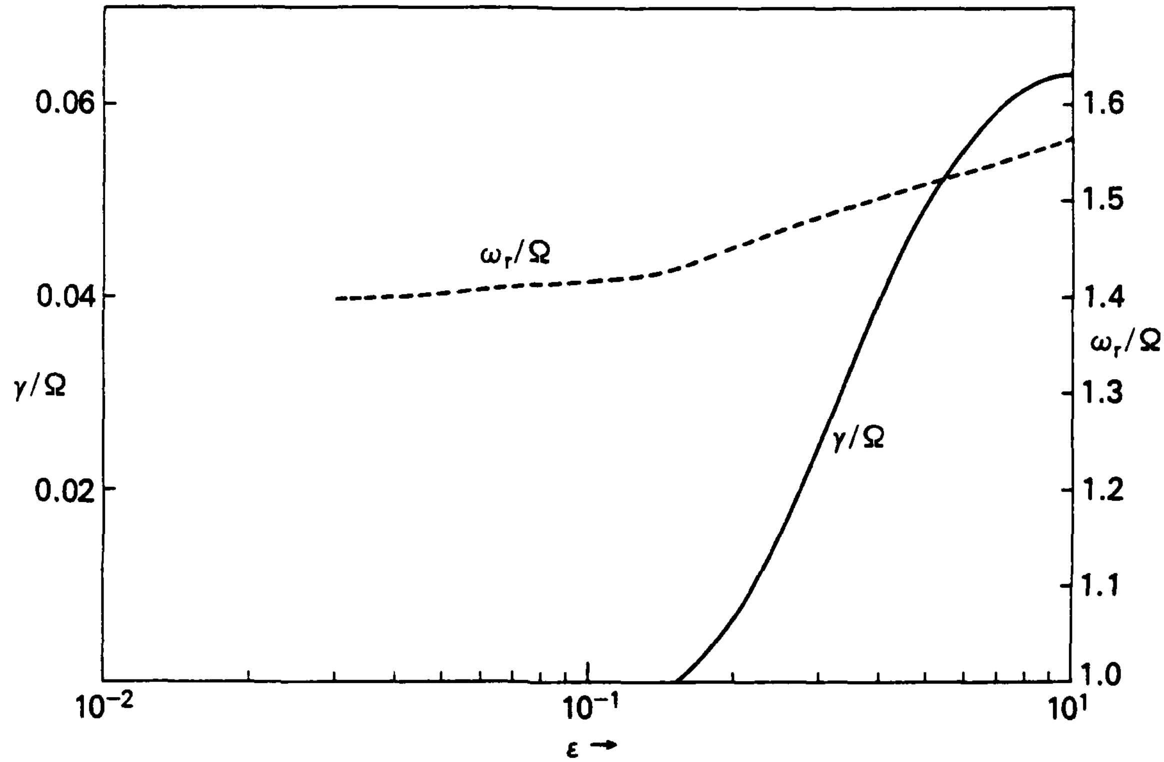

Figure 4. A plot of ω_r/Ω_i and γ/Ω_i against ε. Other parameters are similar to figure 2.

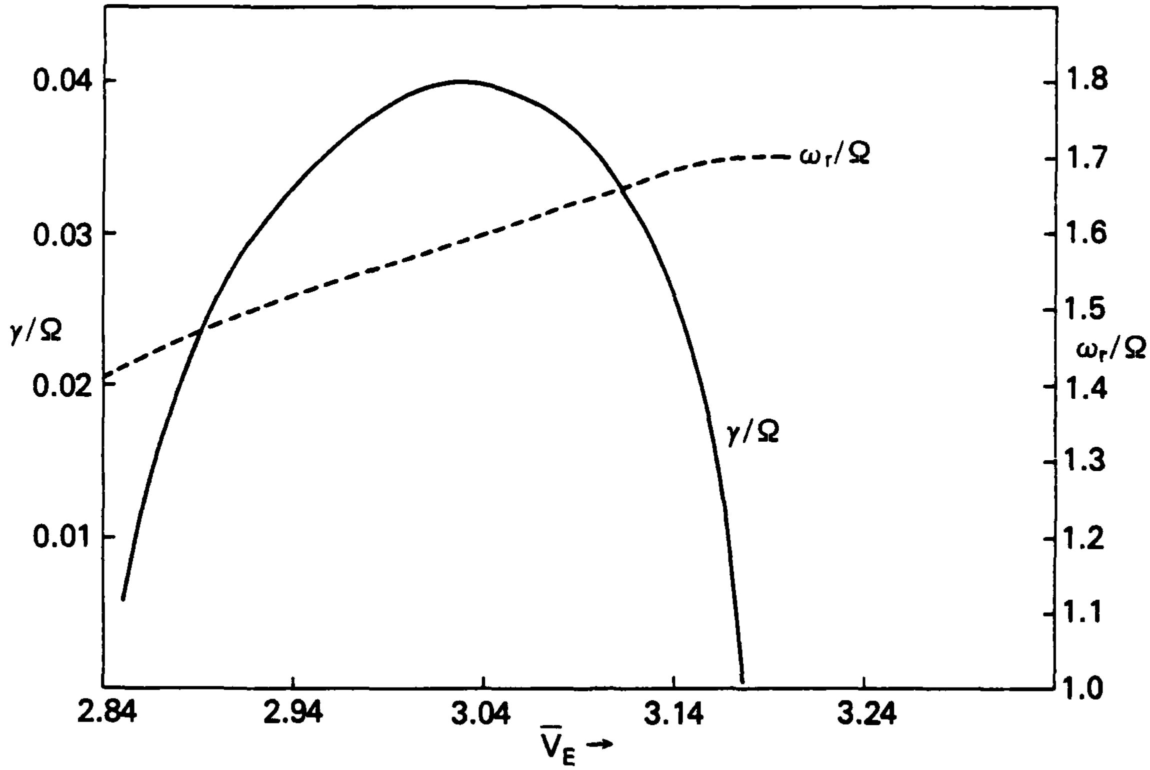

Figure 5. A plot of ω_r/Ω_i against $\overline{V}_E$. Other parameters are similar to the previous figures.

ACKNOWLEDGMENTS

We would like to thank Dr. J.J. Rasmussen of Riso National Laboratory Denmark, Dr. P. Satyanarayana of SAIC for useful discussions and Dr. R.L. Merlino of the University of Iowa for providing useful information regarding the Iowa double layer experiment. This work is supported by the National Aeronautics and Space Administration and the Office of Naval Research.

BIBLIOGRAPHY

1. W.E. Drummond and M.N. Rosenbluth, Phys. Fluids 5, 1507,(1962)

2. R. Hatakeyama and N. Sato, Proc. Plasma Conference, Japan, EP-81-40, p. 31 (1981): M. Nakamura, R. Hatakeyama and N. Sato, Proc. Second Symposium on Plasma Double Layers and Related Topics, p. 171, Innsbruck, Austria (1984)

3. R.L. Merlino, S.L. Cartier, M. Alport and G. Knorr, Proc. Second Symposium on Plasma Double Layers and Related Topics, Innsbruck, Austria (1984).

4. F.S. Mozer, C.W. Carlson, M.K. Hudson, R.B. Torbert, B. Parady and J. Yatteau and M.C. Kelly, Phys. Rev. Lett. 38, 292 (1977): M. Temerin, C. Cattell, R. Lysak, H. Hudson, R.B. Torbert, F.S. Mozer, R.D. Sharp and P.M. Kintner, J. Geophys. Res. 86, 11278(1981).

5. G. Ganguli and P. Bakshi, Phys. Fluids, 25, 1830 (1982).

6. B.B. Kadomtsev, A.B. Mikhailovskii and A.V. Timofeev, Soviet Phys. JETP. 20, 1517 (1965): L.S. Hall and W. Heckrotte, Phys. Fluids, 9, 1496 (1966): A. Bers and S. Gruber, Appl. Phys. Lett. 6, 27 (1965).

7. Y.Y. Lau, C.C. Lin, James W. -K. Mark, Proc. Natl. Acad. Sci. USA, 73, 1379 (1976).

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